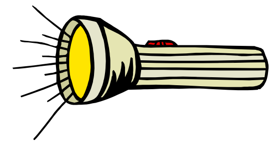
Simple Circuits



Introduction An experimental study of simple circuits can be very useful. First, it represents an excellent opportunity for us to firm up our understanding of the concepts of voltage, current and resistance. Next, it will give us the opportunity to learn about simple devices such as batteries and light bulbs. Knowing something about batteries can be particularly useful these days so two of the goals of this lab are to learn why most batteries fail and how to test a battery. Next, in order to learn more about the physics associated with these devices, we will see how batteries and bulbs are connected in a "standard" flashlight. Finally, we will spend some time learning about *series* and *parallel* arrangements of resistors. Another reason for focusing on simple circuits is that most complicated circuits are merely simple circuits connected together. Consequently, it is impossible to analyze a complicated circuit without understanding the constituent simple circuits.

Theory The most important equation for analyzing circuits, of course, is the fundamental relationship between voltage, V, current, I, and resistance, R.

Text eq. [25.2a] $$R = \frac{V}{I} \qquad (1)$$

Another important equation is the one that describes the power, P, which is the rate at which energy is supplied to a resistor

Text eqs. [25.7a-c] $$P = IV = I^2 R = \frac{V^2}{R} \qquad (2)$$

This can also be interpreted as the rate at which electric potential energy is lost by the charges as they move through the resistor.

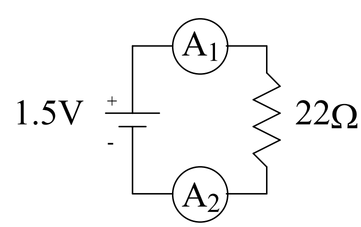
I. The Simplest (?) Circuit We begin the lab with a detailed study of the simple circuit that was introduced in the first laboratory.

A. Current

1. Connect two current probes to the DCA. Be sure that the DCA is correctly connected to the LabPro and that the LabPro is correctly connected to the computer.

2. Boot the computer and start the program **LoggerPro (2.1)**. When the program starts, open the folder **SimpCirc** and open the file **Currents**.

3. When the program is ready and with nothing connected to the current probes (other than the wires from the current probes to the DCA), **Zero** both probes. (Remember that this is accessible by clicking the mouse on **Experiment** in the menu at the top of the computer screen.)



4. Construct the circuit shown at the right.

5. Click on **Collect** to measure the two currents I_1 and I_2. Adjust the vertical scale on the graph so that noise is observable. Either read the currents from the graph or use the **Statistics** function in the **Analyze** menu to obtain a value of the currents. Record the values in the space provided then disconnect the battery.

R1: Depending on the instructions from your instructor, either **Print** the graphs or **Copy** the graphs and **Paste** them into an **Excel** spreadsheet so that the upper left corner of the first one is in cell A1. (Depending on the version of **LoggerPro**, it may be necessary to **Copy** and **Paste** the graphs into **Excel** individually.) If you are using **Excel**, resize the graphs so that the right edges do not extend beyond column J.

(Note: The *total* uncertainty in the current is not equal to the scatter in the data. The scatter just indicates the *precision* of the measurement. There is also uncertainty in the absolute value of the current due to the calibration of the ammeters. It has been determined that the *accuracy* of the current (due to the calibration) is about 2%. We will take the total uncertainty to be the sum of the precision and the accuracy.)

R2: I_1 = ________ ± ________ A R3: I_2 = ________ ± ________ A

6. From the signs of the currents and the directions of the arrows on the current probes, determine the directions of I_1 and I_2.

R4: Draw arrows on the circuit diagram showing the directions of I_1 and I_2 and the direction of the current in the battery and resistor.

The data should show that the current out of the battery (at the positive terminal) equals the current into the battery (at the negative terminal) to within experimental uncertainty i.e. your data should show that $I_1 = I_2$. (It is a common **misconception** that there is less current on the "bottom" of the resistor because a resistor decreases current i.e. it is a **misconception** that charge flows out of a battery and gets "used up" in a resistor.)

R5: Discuss whether the data show that $I_1 = I_2$.

Because $I_1 = I_2$ is an important result, let us do another experiment that should confirm that $I_1 = I_2$.

7. Interchange the positions of the ammeters and reconnect the battery. (The previous ammeter 1 is now ammeter 2 and vice versa.) **Collect** data and record the results as I_1' and I_2'.

R6: Depending on the instructions from your instructor, either **Print** the graphs or **Copy** the graphs and **Paste** them into an **Excel** spreadsheet so that the upper left corner of the first one is in cell K1. If you are using **Excel**, resize the graphs so that the right edges do not extend beyond column T.

R7: I_1' = ________ ± ________ A R8: I_2' = ________ ± ________ A

R9: Discuss whether the data show that $I_1' = I_2'$. (Note: If the calibration of the ammeters is worse than 2%, we might find, for example that $I_1 > I_2$. By reversing the ammeters (making ammeter1 become ammeter 2 and vice versa), if we find that $I_1' < I_2'$, it would show that it is not the currents that are different but, rather, it is the meters that are different.)

R10: Assuming that $I_1 = I_2$, what is the *net charge* supplied by the battery in 1s? Explain.

B. Voltage

1. Use the Protek multimeter ($\overline{\mathrm{V}}$/LOGIC scale) to measure the voltages indicated in the diagram shown below at the right. You may need to review the *Introduction to Electrical Measurements* laboratory to remind yourself of the notation. Record the voltages in the space proved and, to the right of the voltages, identify the circuit element that the voltage is *across*. (The first entry, "battery," is an example.)

R11: V_{ah} = ________ ± ________ V ______battery______

R12: V_{ba} = ________ ± ________ V ________________

R13: V_{cb} = ________ ± ________ V ________________

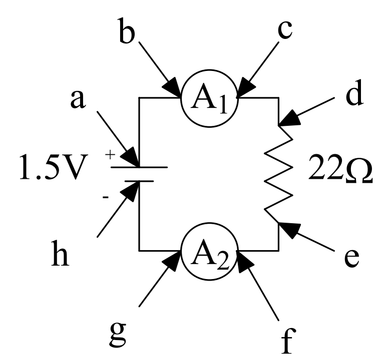
R14: V_{dc} = ________ ± ________ V ________________

R15: V_{ed} = ________ ± ________ V ________________

R16: V_{fe} = ________ ± ________ V ________________

R17: V_{gf} = ________ ± ________ V ________________

R18: V_{hg} = ________ ± ________ V ________________



All of the voltages should be negative or zero except for that across the battery.

R19: What is the meaning of the negative voltages? (Hint: See page 4 of the lab *Introduction to Electrical Measurements*.)

2. In fact, **Kirchhoff's second** or **loop rule** is that *the sum of the changes in potential* (voltages) *around any closed path of a circuit must be zero* (Textbook, page 665). Add up the voltages above and record the answer in the space provided.

R20: Sum of Vs = ________ ± ________ V

R21: Discuss whether the data verify the **loop rule** to within the experimental uncertainty?

C. Resistance of Wires and Ammeters

1. Use the data and eq. (1) to calculate the resistance of a wire. Record the value in the space provided.

R22: R_{wire}(point **c** to point **d**) = ________ ± ________ Ω

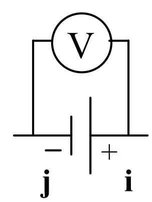
R23: What does the value of R_{wire} imply concerning the resistance of wires?

2. Use the data and eq. (1) to calculate the resistance of an ammeter. Record the value in the space provided.

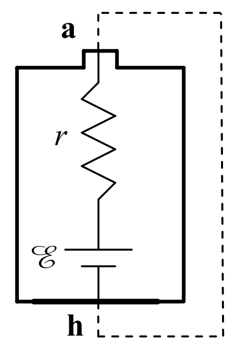
R24: $R_{ammeter}$(point **b** to point **c**) = ________ ± ________ Ω

R25: What does the value of $R_{ammeter}$ imply concerning the resistance of an ammeter?

II. Internal Resistance of a Battery (Text page 659)



1. Disconnect the battery from the circuit and, as shown at the right, measure the voltage, V_{ij}, across the battery while it is not connected to a circuit. (Yes, we did this in the first laboratory.) Record the value in the space provided. We will take this to be equal to the emf of the battery i.e. $V_{ij} = \mathscr{E}$.



R26: $\mathscr{E}$ = ________ ± ________ V

The emf, $\mathscr{E}$, should be larger than the value of V_{ah} (measured in Part B of Section I) which is the voltage across the battery when the battery is creating current. (If your value of $\mathscr{E}$ is not larger than V_{ah}, consult your instructor.)

Since $\mathscr{E} > V_{ah}$, we must conclude that some negative voltage is produced inside the battery is creating current. In section 26-1 of the textbook, it is pointed out that this is because there is internal resistance, r, inside the battery. In fact, all batteries can be represented as shown in the diagram. Consequently, if there is a current, I, upward (from bottom to top or from point **h** to point **a**), then the voltage that appears across the terminals of the battery (the **terminal voltage**) is given by

$$V_{ah} = \mathcal{E} - Ir \qquad (3)$$

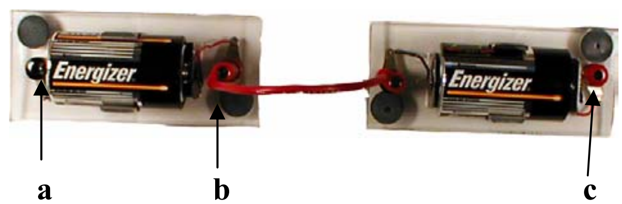
2. Use the data and eq. (3) to calculate the internal resistance of the battery and record the value in the space provided.

R27: r = ________ ± ________ Ω

This is important because most batteries "go dead" because the internal resistance increases, *not* because the emf decreases. Consequently, in order to "test" a battery it must be supplying a current. When there is current, one can either measure the voltage or the current. If either is low, the battery is "dead."

III. Batteries in a Flashlight Next, we study the operation of a standard flashlight. A standard flashlight requires 2 D-cell batteries. The batteries are placed in the flashlight "one after another" and thus we say that the batteries are in *series*. Let us study the consequence of placing batteries in series.

1. Connect the opposite end of two batteries together as shown in the diagram. For convenience, place the positive end at the right.



2. Measure the voltages V_{ba}, V_{cb} and V_{ca} and record the values in the space provided.

R28: V_{ba} = ________ ± ________ V R29: V_{cb} = ________ ± ________ V

R30: V_{ca} = ________ ± ________ V

3. Add the values V_{cb} and V_{ba} and record the sum in the space provided.

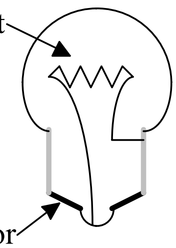
R31: $V_{cb} + V_{ba}$ = ________ ± ________ V

R32: How does the sum compare with the value of V_{ca}?

R33: Consider the electric potential energy of a charge that travels through the batteries from point **a** to point **c** and explain why the total voltage is equal to the sum of the voltages for batteries in series.

IV. Flashlight Bulbs Next, we will study the bulbs used in flashlights. A diagram of the cross section of a bulb is shown at the right. The bulb should be a number 14 (#14). The number usually appears on the metal casing on the light bulb.

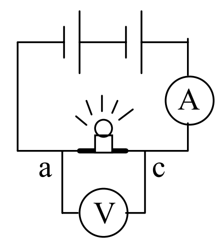
1. Study the diagram and the #14 bulb and decide where connections to the bulb must be made in order to make the bulb light. (Hint: The charge must flow through the filament and that is drawn as a resistor in the diagram.) As a test of your understanding, remove the bulb from the holder and use one battery and one wire to light the bulb. At the right, make a sketch of your solution.



2. Use the Mastech multimeter to measure the resistance of the filament of the bulb and record the value in the space provided. (Since the resistance is very low, on the order of 1 Ω, it is important for the leads to make good contact to the bulb.)

R34: $R_{\text{bulb not glowing}}$ = ________ ± ________ Ω

3. Use the batteries in series to light the bulb (make a flashlight) as shown at the right.



4. Use the computer/DCA to measure the current in the circuit and use the multimeter to measure the voltage across the light bulb. (Note that the multimeter and ammeter are very sensitive so that very small changes in current or voltage are observable. However, if the current or voltage drifts more than you think that it should, consult your instructor.) Record the values in the space provided.

R35: V_{ca} = ________ ± ________ V R36: I = ________ ± ________ A

5. Use these values of V_{ca} and I and eq. (1) to calculate the resistance of the light bulb and record the value in the space provided.

R37: $R_{\text{bulb when glowing}}$ = ________ ± ________ Ω

6. $R_{\text{bulb when glowing}}$ should be much larger than $R_{\text{bulb not glowing}}$. That is because when the bulb is glowing the filament is very hot. As discussed on page 641 in the textbook, what happens is that the resistance of metals (such as the tungsten filament) increases as temperature increases. The reason is that resistance is caused by collisions between the electrons and the ions in the metal. Because the ions have more thermal energy, there are more collisions at high temperature and thus the resistance is higher. In fact, the data can be used to calculate the temperature of the bulb when it is glowing. In Ex. 25-6 in the textbook, it is pointed out that eq. [25-5] can be written as

$$R = R_o\,[1 + \alpha\,(T - T_o)] \tag{4}$$

R_o is the resistance at room temperature. For our experiment, this is the resistance of the bulb measured by the multimeter i.e. $R_o = R_{\text{bulb not glowing}}$. R is the resistance at high temperature. For our experiment, this is the resistance when the filament is glowing i.e. $R = R_{\text{bulb when glowing}}$. Next,

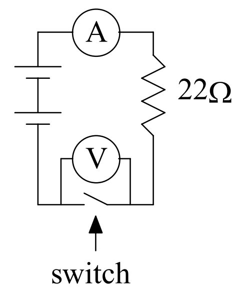
T_o is room temperature and T is the temperature of the filament while it is glowing. Finally, it is given in Table 25-1 in the textbook that for tungsten wire $\alpha = 0.0045\ (\mathrm{C}°)^{-1}$. Use the data and eq. (4) to calculate T. Show your calculation and record the value in the space provided.

R38: T = ________ ± ________ °C

Yes, the temperature should be very high. For comparison, the melting point of tungsten is (3410 ± 20)°C. A high temperature is necessary for the filament to emit large amounts of visible light.

Note that because of the high temperature involved, it takes several seconds for a light bulb to reach thermal equilibrium. This explains some of the drift in the voltage and current associated with lighting a bulb.

V. Switches To firm up our understanding of the voltage and current in a simple circuit, let us add a switch and make some measurements of the current as the switch is opened and closed.



1. Replace the current probe in PROBE1 on the DCA with a voltage probe.

2. Open the file **VoltCurr**.

3. With the voltage probe leads connected together (shorted out) and the current probe disconnected from any circuit, **Zero** both probes.

4. Construct the circuit shown in the diagram.

5. Click the mouse on **Collect** and while the computer is collecting data, open and close the switch in approximately one second intervals.

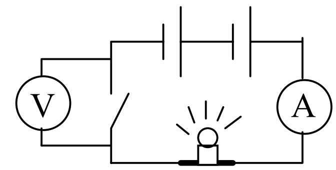
R39: Depending on the instructions from your instructor, either **Print** the graphs or **Copy** the graphs and **Paste** them into an **Excel** spreadsheet so that the upper left corner of the first one is in cell U1. If you are using **Excel**, resize the graphs so that the right edges do not extend beyond column AD.

R40: On the graph, indicate when the switch is open and when the switch is closed. (This is easy to do in **Excel**.)

R41: What is the voltage across the switch when the switch is open? Explain.

R42: What is the voltage across the switch when the switch is closed? Explain.

6. Replace the resistor in the last circuit with a light bulb as shown in the next diagram.



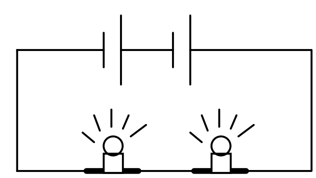
7. Carry out the same experiment as above i.e. while the computer is collecting data, open and close the switch in approximately one second intervals.

R43: Depending on the instructions from your instructor, either **Print** the graphs or **Copy** the graphs and **Paste** them into an **Excel** spreadsheet so that the upper left corner of the first one is in cell AE1. If you are using **Excel**, resize the graphs so that the right edges do not extend beyond column AN.

R44: Explain the difference in the shapes of the curves for the light bulb and the resistor. (Hint: Think temperature and resistance.)

VI. Bulbs and Batteries Revisited As a prelude to the lab *Kirchhoff's Laws*, we will study bulbs and batteries in series and parallel.

A. Bulbs in Series and Batteries in Series



1. Connect two bulbs in series in series with two batteries in series as shown at the right.

R45: Compare the brightness of these bulbs with the brightness of a single bulb in the same circuit (as observed in the previous experiment). Explain.

2. Remove one of the bulbs from its socket.

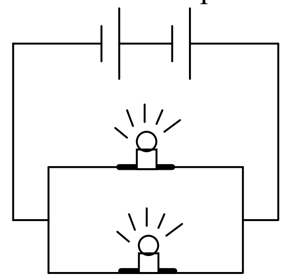
R46: What happens to the brightness of the other bulb? Explain.

B. Bulbs in Parallel and Batteries in Series

Note Please minimize the time that you take for this experiment.

1. Connect two bulbs in parallel. Connect the bulbs in series with batteries in series as shown in the next diagram.

R47: Compare the brightness of these bulbs with the brightness of the bulbs in the previous experiment. Explain.

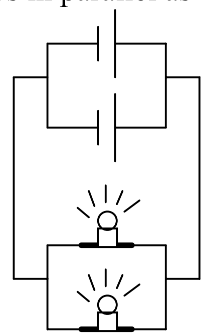


2. Remove one of the bulbs from its socket.

R48: What happens to the brightness of the other bulb? Explain.

C. Batteries in Parallel and Bulbs in Parallel

1. Connect two batteries in parallel. Connect the batteries in series with bulbs in parallel as shown in the next diagram.



R49: Compare the brightness of these bulbs with the brightness of the bulbs of the previous experiment (batteries in series). Explain.

2. Remove one of the light bulbs from its socket.

R50: What happens to the brightness of the other bulb? Explain.

3. Replace the light bulb then remove one battery.

R51: What happens to the brightness of the bulbs. Explain. (Note: If the brightness of the light bulbs changes when one battery is removed, one of the batteries is weak and should be replaced.)

End of Lab Checkout Before leaving the laboratory, please dismantle any circuits or connections that you have made. Place the wires in one pile and return the meters to their boxes. Show your instructor that the screen saver on the computer is the same as when you entered lab.